

A BRIEF HISTORY OF FINGER ARTHROPLASTY

Richard A. Berger, M.D., Ph.D.

Department of Orthopaedic Surgery
University of Iowa Hospitals and Clinics
Iowa City, Iowa 52242

INTRODUCTION

Almost every orthopaedic surgeon has had the opportunity to evaluate and treat patients with osteoarthritic and rheumatoid hand deformities. Distal to the wrist, these deformities are found primarily in the metacarpophalangeal (MCP) and proximal-interphalangeal (PIP) joints. Arthroplastic intervention has now become commonplace for severe deformities of these joints; however, this has not always been true. As recently as 1954, Smith-Peterson was advocating nonoperative management for arthritic hand deformities, claiming that surgical correction of more proximal joints, such as the elbow and shoulder, would prevent the "gravity" induced deformities commonly found in the hand³⁵.

In the rare cases of arthritic distal-interphalangeal (DIP) joints of the hand symptomatic enough to warrant operative intervention, arthrodesis has been recommended as the procedure of choice. Also, reports of silicone rubber arthroplasty have been published². Arthrodesis of the more commonly affected PIP or MCP joints carries significant functional limitations and has not been recommended under most clinical circumstances. Over the past 70 years, a significant effort has been made to develop surgical procedures that will provide patients with painless and functional MCP and PIP joints. The purpose of this manuscript is to outline the history of the development of these procedures.

RESECTION/INTERPOSITION ARTHROPLASTY

Prior to 1914, arthrodesis was the most commonly employed treatment for severe arthritic conditions of the PIP joint. Bunnell felt that this was the treatment of choice in an ankylosed and malpositioned joint (6). However, the period around World War I witnessed a new demand for improving functional range of motion in patients with severe post-traumatic degenerative changes in the PIP joint. Numerous anecdotal reports surfaced from 1914 through 1925 describing limited experience with resection arthroplasty with various soft tissue interposition techniques.

In 1950, Liebolt reported his results from procedures to improve motion in ankylosed PIP and MCP joints in soldiers injured in World War II²⁸. He refined the procedure into two stages. The first stage was a capsulectomy, in which the collateral ligaments were also divided. When

there was obvious destruction of the articular cartilage radiographically, resection of either the proximal or distal surface of the joint with interposition of ulnar fascia was indicated. A postoperative range of motion from 30 degrees extension to 70 degrees flexion could be anticipated. Carroll (1954) described his resection arthroplasty technique without soft tissue interposition combined with long-term postoperative digital traction in 30 patients with ankylosed PIP joints¹¹. His prerequisites for surgery included severe joint deformity, an intact extrinsic tendon apparatus and strong patient motivation. He reported fair to good results in 80% of his patients, with instability not being a major postoperative complaint.

Resection arthroplasty of the MCP joint was first reported by Fowler in 1962 and followed by Tupper and Vainio, using a variety of resection and interposition techniques (Fig. 1)^{18,41}. These techniques offer a satisfactory method of reducing pain in a severely degenerated MCP joint, yet they are considered to result in a high degree of joint instability and have been reserved largely for salvage situations.

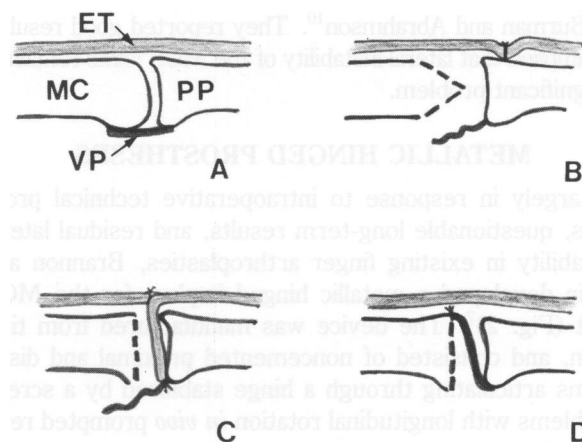


Figure 1 A-D

(A): Normal joint schematic showing the metacarpal (MC), proximal phalanx (PP), extensor tendon (ET) and volar plate (VP). (B-D): Schematic of metacarpophalangeal joint resection arthroplasties. The dotted line represents the metacarpal osteotomy. (B) Fowler. (C) Vainio. (D) Tupper. (after Flatt, A.E. "The Pathomechanics of Ulnar Drift" Final Report, Social and Rehabilitation Services Grant No. R02226M, 1971, p. 103.)

TRANSPLANT ARTHROPLASTY

The concept of transplanting articular surfaces in the finger joints was introduced by Wolff in 1910. He reported excellent results in a female with tuberculosis involving one of her proximal phalanges in whom he resected the entire proximal phalanx and autotransplanted the proximal phalanx of the 2nd toe. One year later, Goebel reported removing an entire proximal phalanx for treatment of an enchondroma, replacing it with an autologous transplant of the 2nd toe proximal phalanx. Postoperatively, the patient was noted to have active flexion of all finger joints, but was noted to be quite limited functionally. Oeleker performed an entire joint cadaver transplant in a patient with an ankylosed PIP joint caused by a gunshot wound, obtaining excellent results. In 1948, Riordan and Graham reported several cases of autologous partial transplants, in which the metacarpal heads were resected and replaced by 4th metatarsal heads. They reported satisfactory ranges of motion and no radiographic evidence of degenerative changes at one year follow-up. In 1954, Graham performed an entire thumb MCP joint autotransplant in a three year old boy injured in a washing machine wringer accident. The joint was replaced with a 4th MTP joint, and at 22 month follow-up examination revealed satisfactory range of motion and continued growth at the physal plates.

"CAP" ARTHROPLASTY

Encouraged by Smith-Peterson's results of Vitallium cup arthroplasty of the hip, Burman performed a Vitallium "cap" arthroplasty for a severely degenerated metacarpal head in 1940⁹. In 1943, a methylmethacrylate "cap" for degenerated metacarpal heads was used in two patients by Burman and Abrahamson¹⁰. They reported good results, but implied that lateral instability of the MCP joints remained a significant problem.

METALLIC HINGED PROSTHESES

Largely in response to intraoperative technical problems, questionable long-term results, and residual lateral instability in existing finger arthroplasties, Brannon and Klein developed a metallic hinged implant for the MCP joint (Fig. 2)⁷. The device was manufactured from titanium, and consisted of noncemented proximal and distal stems articulating through a hinge stabilized by a screw. Problems with longitudinal rotation *in vivo* prompted revision of the stems into a more triangular cross-sectional shape. Additionally, significant bony resorption occurred around the stems, which prompted further revision allowing fixation to the adjacent bone with staples. They reported their experience in 14 patients at a maximum of three year follow-up. All patients were felt to have functional ranges of motion and no lateral instability. All patients showed

radiographic evidence of bone resorption and "settling" of the prosthesis. Two patients experienced asymptomatic screw loosening, and one patient was noted to have asymptomatic penetration of one of the stems into an adjacent joint space. One patient complained that small metallic objects were attracted to his finger post-operatively. No evidence of tissue reaction to titanium was noted.

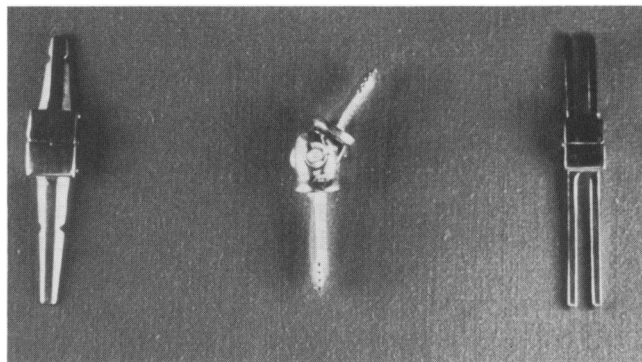


Figure 2

Metallic hinged prostheses. Left to right: Brannon, Richards and Flatt designs. There is no clinical data available on the Richards prosthesis. (Courtesy of Department of Orthopaedic Surgery Archives, University of Iowa College of Medicine.)

Flatt felt that the rotational instability of the Brannon prosthesis remained unacceptable, in spite of the revision of stem shape. In 1959, he began implanting a double-pronged, hinged metal prosthesis for MCP and PIP joints (Fig. 2). This design theoretically reduced the tendency of longitudinal rotation and allowed bony ingrowth between the prongs. At 14 years follow-up of 167 MCP and 75 PIP implants, 10% of the prostheses were removed because of infection, failure of the screws, fracture of prongs, skin breakdown, periarticular fibrosis, or severe settling and bone resorption¹⁷. Independent reviews by Zachariae as well as by Girzadas and Clayton confirmed major problems due to significant bone resorption with subsequent shift of the Flatt prostheses^{21,43}. Blair et al. reviewed patients with Flatt MCP and PIP prostheses and reported high patient satisfaction in spite of major complications^{5,14}.

POLYETHYLENE-METAL PROSTHESES

Almost simultaneously, several "2nd generation" finger joint prostheses appeared, each made of a proximal stem composed of polyethylene which articulated with a metallic distal stem (Fig. 3). Each stem was designed to be cemented in the medullary canal of the respective bone. The St. Georg-Buchholz design incorporated a fixed center of rotation with two models differing only in the range of allowed radial-ulnar deviation (Fig. 3). Gillespie et al., in their study of the characteristics of several "2nd generation" prostheses in cadaver fingers, found that the passive range of motion of the St. Georg-Buchholz prosthesis

averaged 45 degrees to 160 degrees and allowed 5 to 15 degrees of radio-ulnar deviation²⁰. Also noted was significant cold flow of the polyethylene hinge resulting in permanent deformation. The Schultz prosthesis had a changing center of rotation by incorporating a slot in the articulation of the polyethylene component, which allowed the distal metal articulation to glide as the joint was rotated (Fig. 3). Gillespie et al. measured an average range of motion from 0 to 90 degrees and 8 degrees radio-ulnar deviation in implanted Schultz prostheses in cadaver fingers²⁰. The Strickland prosthesis offered a fixed center of rotation and an ulnar "shoulder" in the polyethylene articulation which theoretically resisted ulnar deviation of the distal metallic stem (Fig. 3). Gillespie et al. reported a range of motion averaging 5 to 90 degrees, and found an average range of radial-ulnar deviation of 15 deg. in extension and 0 degrees in flexion of the prosthesis²⁰.

In 1964, Steffee et al. designed a prosthesis with a Teflon proximal stem which was later revised to high-density polyethylene²⁹. Following trials in cadavers and chimpanzees, this prosthesis, Model I, was implanted in humans in 1968. Production was delayed until 1974, in part because of the initial success of the silastic joint replacements. Model II (Fig. 3), developed in the interim, included a volar offset center of rotation to increase the extensor moment arm (to prevent recurrence of boutonniere deformities) and a longer distal stem to counter the tendency to tilt volarward. Clinical trial reports by Steffee et al. included 160 Model I implants and 272 Model II implants, with 55% and 86% satisfactory results respectively. Overall, pain relief was found in 94% of the trials and correction of ulnar deviation in 87%³⁸. At two year follow-up, there were 2 infections, 2 dislocations and 2 fractured polyethylene components at the level of the articulation. Radiographic loosening of the distal component was noted in 18% of the fingers.

Overall, Gillespie et al. found that the polyethylene-metal prostheses were unforgiving in terms of placement error, that the polyethylene had a strong tendency to deform under physiologic loading conditions, and measured fingertip forces generally fell below baseline levels²⁰.

SILICONE RUBBER PROSTHESES

Silicone rubber (silastic) was introduced as a material for use in finger arthroplasty almost simultaneously by Swanson and Niebauer in the early 1960's. Swanson cited several theoretical advantages for using Silastic over other materials including heat stability, durability, excellent flexion characteristics and force dampening properties, biologic inertness, low cost of production, and ease of handling³⁶. It was noted, however, that Silastic tears easily when its surface is lacerated. Swanson began development of his MCP and PIP implants in 1962, with over 10,000 implants placed less than a decade later. The basic design of the Swanson MCP and PIP implants is a single Silastic unit with tapered proximal and distal stems and a dorsally offset flexion region (Fig. 4). Swanson described two processes that occur with implantation, theoretically enhancing performance of the implant. The first process is "encapsulation" or development of a fibrous joint capsule surrounding the implant which enhances joint stability. The process of encapsulation occurs in part because of the "intrinsic dynamic spacer" function of the implant. The second process is the "piston effect", or the gliding motion of the stems within the medullary canals during flexion and extension of the joint. Theoretically, the piston effect increases the lifespan of the implant because forces are dispersed over a broad area of the implant. Gliding also allows a greater range of motion. In his first report of nearly 4000 MCP implants, Swanson listed 96 complications, including 1% fractures, 0.7% infections and 0.8% dislocation rates³⁶. Similar complication rates were noted for the PIP arthroplasties³⁷. Despite the low complication rate reported for both implants, 10% were revised in a series of patients followed for at least one year. In other studies, Swanson-design finger joint implants were shown to have fracture rates ranging between 9% and 44%, recurrence of ulnar drift in up to 43%, low infection rates, up to 24% incidence of peri-implant bone resorption and evidence of silicone synovitis. Common to all reports was a sense of high patient satisfaction with the procedure^{1,3,4,15,39,40}. In their study of Swanson-design PIP joint implants, Dryer et al. found post-operative swan-neck or boutonniere deformities in 37% of patients evaluated¹⁴. Gillespie et al., in their biomechanical study of finger joint implants found the range of motion to average -30 to 90 degrees with an unpredictable range of radio-ulnar deviation²⁰ and an erratic center of rotation. The majority of motion occurred at the bone-implant interface,

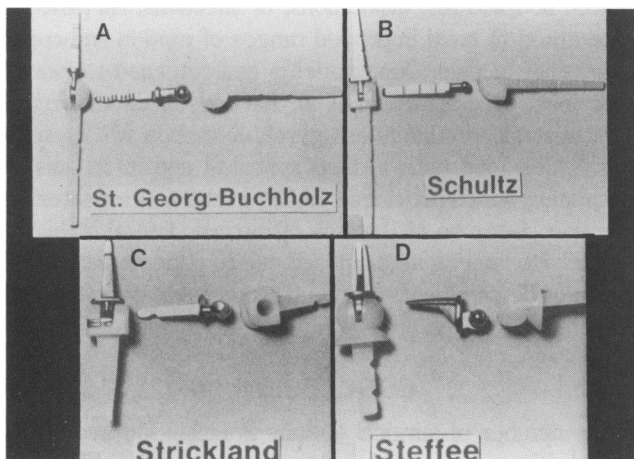


Figure 3A-D

Polyethylene-metal prostheses. (Reprinted from Gillespie et al., *J. Hand Surg.*, 6:512, 1979.)

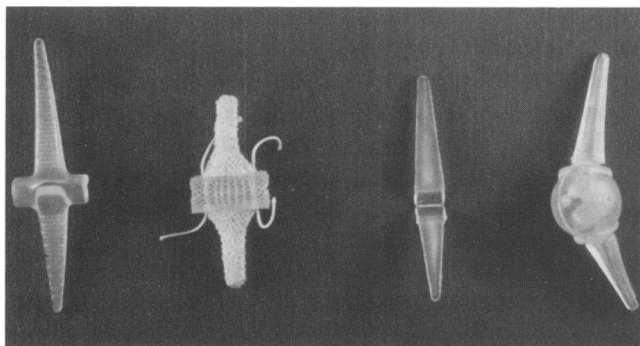


Figure 4

Silicone rubber prostheses. Left to right: Swanson, Niebauer, Reis-Calnan and Nicolle-Calnan designs. (Courtesy of Department of Orthopaedic Surgery Archives, University of Iowa College of Medicine.)

rather than at the hinge region of the implant. Interestingly, they also found that the implant behaved independent of its orientation. The measured parameters were statistically unchanged with the implant right side up, upside down or rotated axially 90 degrees. Recently, the Silastic has been upgraded in an effort to reduce the incidence of fractures propagated through surface lacerations. Additionally, metallic grommets have been introduced to reduce shearing at the bone-implant interface.

Niebauer et al. began work on a Dacron covered Silastic finger joint implant in 1966, with the idea for this construction stemming from the clinical success noted in Dacron covered Silastic used in prosthetic heart valves³¹. The first design consisted of wide stems covered with Dacron leading to a bare hinge region (Fig. 4). Of 165 MCP and 13 PIP implants utilizing the first design, complications included infections, buckling of the prosthesis and resorption at the bone-implant interface. Clinically, MCP total range of motion averaged 40 degrees. The basic design was revised narrowing the stems near the hinge region, increasing the size of the hinge region and providing Dacron tethers for bony fixation of the prosthesis. Of 89 MCPs implanted with the revised model, Niebauer et al. reported recurrent ulnar drift of less than 20 degrees in 64% (greater than 35 degrees in 20%), pain relief in 84%, subluxation in 58%, severe bone destruction in 43%, and a 12% major complication rate including infection and unacceptable subluxation¹². Patient satisfaction was high with 64% noting significant improvement after implantation. In a follow-up of 441 MCP implants, Goldner found similar results, including a 68% patient satisfaction rate; however, he noted significant lateral instability²². In their biomechanical study, Gillespie et al. found an erratic center of rotation and consistent buckling of the implants at the bone-implant interface (exaggerated with the revised model)²⁰. Additionally, after physiologic loading a 20% stretch of the Dacron suture used to fix the implant to the bone occurred, which they felt would effectively negate any

bone fixation attained at the time of implantation.

The Reis-Calnan finger joint implant incorporated polypropylene stems to increase their stiffness and strength reducing the tendency for the prosthesis to buckle at the bone-implant interface³³. Nicolle and Calnan modified this design by adding a Silastic capsule at the hinge region to reduce soft tissue entrapment and to increase the moment arm for the extensor tendons crossing the joint (Fig. 4)³⁰. In their report of 68 implants at less than one year follow-up, there were no infections, fractures or cases of loosening; however, three joints remained painful. Other designs incorporating Silastic materials are appearing, such as the Sutter Biomedical Inc. MCP implant. It claims to have an enhanced range of motion, increased stability, and improved mechanical advantages. At the time of this writing, however, no clinical trials are available for review.

NEW DESIGNS

Dissatisfaction with the performance of currently available finger joint implants has motivated numerous investigative groups to design new implants, utilizing more sophisticated design techniques and materials. For example, Weightman et al. have published a new MCP prosthesis design, utilizing sophisticated biomechanical input parameters and testing systems⁴². The design incorporates paired prostheses joined by common hinge pins which theoretically reduce the tendency for recurrent ulnar drift to occur, reduce the torque applied to the individual prostheses, and retard loosening of the implants. No clinical trials have been reported to date. As in the hip, knee, shoulder and elbow, the concept of biologic fixation of prostheses through bony ingrowth has been incorporated into the design of new finger joint prostheses. Doi. et al. have designed a hinged prosthesis composed of alumina ceramics and high density polyethylene¹³. Preliminary clinical results on 13 patients at one to three year follow-up showed no fractures, dislocations, or infections. All patients were noted to have improved ranges of motion and complete relief of pain. Nine patients had returned to heavy labor jobs. Beckenbaugh et al. have been developing a semiconstrained cementless pyrolytic carbon MCP prosthesis, designed with a deep spherical cup in the distal component which provides stability in the anteroposterior direction. Because of the lack of intrinsic lateral stability, they advise limiting its proposed use to patients with minimal joint deformities². Currently, no clinical data is available on this implant.

CONCLUSION

The number of surgical options available for treatment of arthritic metacarpophalangeal and proximal interphalangeal joint deformities is impressive. However, it seems that much work remains to improve further function and

biocompatibility of joint implants. The Silastic joint implants are currently widely used with proven clinical success, low tissue reactivity (in most circumstances), relative low cost and high patient satisfaction. It will be very interesting to follow the developmental progress of the newest generation of implants, which seem to have in common cementless fixation and relatively constrained kinematics.

BIBLIOGRAPHY

1. Beckenbaugh, R.D.; Dobyns, J.H.; Linscheid, R.L.; and Bryan, R.S.: Review and Analysis of Silicone-Rubber Metacarpophalangeal Implants. *J. Bone and Joint Surg.*, 58-A:483, 1976.
2. Beckenbaugh, R.D., and Linscheid, R.L.: "Arthroplasty in the Hand and Wrist" in *Operative Hand Surgery*, Green, D.P. (Ed), 2nd Ed. pp 168-169, 183-184, New York, Churchill Livingstone.
3. Bieber, E.J.; Weiland, A.J.; and Volenec-Dowling, S.: Silicone-Rubber Implant Arthroplasty of the Metacarpophalangeal Joint for Rheumatoid Arthritis. *J. Bone and Joint Surg.*, 68A:206, 1986.
4. Blair, W.F.; Shurr, D.G.; and Buckwalter, J.A.: Metacarpophalangeal Joint Implant Arthroplasty with a Silastic Spacer. *J. Bone and Joint Surg.*, 66-A:365, 1984.
5. Blair, W.F.; Shurr, D.G. and Buckwalter, J.A.: Metacarpophalangeal Joint Arthroplasty with a Metallic Hinged Prosthesis. *Clin. Ortho.*, 184:156, 1984.
6. Boyes, J.H.: "Bunnell's Surgery of the Hand". 5th Ed., p. 326, Philadelphia, J.B. Lippincott.
7. Brannon, E.W., and Klein, G.: Experience with a Finger-Joint Prosthesis. *J. Bone and Joint Surg.*, 41-A:87, 1959.
8. Brocq, M.P.: Ankyloses vicieuses du coude et du medius. Resection avec interposition fibreuse. Resultats eloignes. *Bull. et Mem. Soc. Nat. de Chir.*, 52:1048, 1926.
9. Burman, M.S.: Vitallium Cap Arthroplasty of Metacarpophalangeal and Interphalangeal Joints of the Fingers. *Bull. Hosp. Joint Dis.*, 1:79, 1940.
10. Burman, M.S., and Abrahamson, R.H.: The Use of Plastics in Reconstructive Surgery. Lucite in Arthroplasty. *Mil. Surg.*, :405, 1943.
11. Carroll, R.E., and Taber, T.H.: Digital Arthroplasty of the Proximal Interphalangeal Joint. *J. Bone and Joint Surg.*, 36-A:912, 1954.
12. Derkash, R.S.; Niebauer, J.J.; and Lane, L.S.: Long-term Follow-up of Metacarpophalangeal Arthroplasty with Silicone Dacron Prosthesis. *J. Hand Surg.*, 11A:553, 1986.
13. Doi, K.; Kuwata, N; and Kawai, S.: Alumina Ceramic Finger Implants: A Preliminary Biomaterial and Clinical Evaluation. *J. Hand Surg.*, 9A:740, 1984.
14. Dryer, R.F.; Blair, W.F.; Shurr, D.G.; and Buckwalter, J.A.: Proximal Interphalangeal Joint Arthroplasty. *Clin. Orthop.*, 185:187, 1984.
15. Ferlic, D.C.; Clayton, M.L.; and Halloway, M.: Complications of Silicone Implant Surgery in the Metacarpophalangeal Joint. *J. Bone and Joint Surg.*, 57A:991, 1975.
16. Flatt, A.E.: Restoration of Rheumatoid Finger-Joint Function. *J. Bone and Joint Surg.*, 43-A:753, 1961.
17. Flatt, A.E., and Ellison, M.R.: Restoration of Rheumatoid Finger Joint Function. A Follow-up Note After Fourteen Years of Experience With A Metallic-hinged Prosthesis. *J. Bone and Joint Surg.*, 54-A:1317, 1972.
18. Fowler, S.B.: Arthroplasty of Metacarpophalangeal Joints in Rheumatoid Arthritis. *J. Bone and Joint Surg.*, 44-A:1037, 1962.
19. Gallagher, P.: An Aid to A Good Functional Result in Arthroplasties on A Digit. *J. Am. Med. Assn.*, 65:1180, 1915.
20. Gillespie, T.E.; Flatt, A.E.; Youm, Y.; and Sprague, B.L.: Biomechanical Evaluation of Metacarpophalangeal Joint Prosthesis Designs. *J. Hand Surg.*, 6:508, 1979.
21. Girzadas, D.V., and Clayton, M.L.: Limitations of the Use of Metallic Prosthesis in the Rheumatoid Hand. *Clin. Orthop.*, 67:127, 1969.
22. Goldner, J.L.; Gould, J.S., Urbaniak, J.R.; and McCollum, D.E.: Metacarpophalangeal Joint Arthroplasty with Silicone-Dacron Prostheses (Niebauer type): Six and a Half Years' Experience. *J. Hand Surg.*, 2:200, 1977.
23. Graham, W.C.: Transplantation of Joints to Replace Diseased or Damaged Articulations in the Hands. *Am. J. Surg.*, 88:136, 1954.
24. Hamilton, G.: Arthroplasty of the Thumb and Finger Joints. *Texas J. Med.*, 14:353, 1919.
25. Hesse, E.: Beitrage zur Frage der operativen Mobilisierung versteifter Fingergelenke. *Arch. F. Klin. Chir.*, 119:1, 1922.
26. Knavel, A.B.: Infections of the Hand. Ed. 5, pp. 448-449, Philadelphia, Lea and Febiger, 1925.
27. Lexer, E.: Wiederherstellung-Chirurgie, S. 200-201. Leipzig, J.A. Barth, 1920.
28. Liebolt, F.L.: The Use of Capsulectomy and Arthroplasty for Limitation of Finger Motion. *Surg., Gyn. and Obst.*, 90:103, 1950.
29. Linscheid, R.L.: Preliminary Results With Steffee Arthroplasty in Rheumatoid Arthritis (abstract). *Clin. Orthop.*, 119:273, 1976.
30. Nicolle, F.V., and Calnan, J.S.: A New Design of Finger Joint Prosthesis for the Rheumatoid Hand. *Hand*, 4:135, 1972.
31. Niebauer, J.J., and Landry, R.M.: Dacron-Silicone Prosthesis for the Metacarpophalangeal and Interphalangeal Joints. *Hand*, 3:55, 1971.

- ³² Payr, E.: Weitere Erfahrungen uber die operative Mobilisierung ankylosierter Gelenke, mit Berucksichtigung des spateren Schickals der Arthroplastik. Deutsche Zeitschr. f. Chir., 129:341, 1914.
- ³³ Reis, N.D., and Calnan, J.S.: Integral Hinge Joint. Ann. Rheum. Dis., 28(Suppl. 5):59, 1969.
- ³⁴ Riordan, D.C., and Fowler, S.B.: Surgical Treatment of Rheumatoid Deformities of the Hand (abstract). J. Bone and Joint Surg., 40-A, 1958.
- ³⁵ Smith-Petersen, M.N.; Aufranc, O.E.; and Larson, C.B.: Useful Surgical Procedures For Rheumatoid Arthritis Involving Joints of the Upper Extremity. Arch. Surg., 46:764, 1943.
- ³⁶ Swanson, A.B.: Flexible Implant Arthroplasty for Arthritic Finger Joints. J. Bone and Joint Surg., 54-A:435, 1972.
- ³⁷ Swanson, A.B.; Maupin, B.K.; Gajjar, N.V.; and de Groot Swanson, G.: Flexible Implant Arthroplast in the Proximal Interphalangeal Joint of the Hand. J. Hand Surg., 10A:797, 1985.
- ³⁸ Steffee, A.D.; Beckenbaugh, R.D.; Linscheid, R.L.; and Dobyns, J.H.: The Development, Technique, and Early Clinical Results of Total Joint Replacement for the Metacarpophalangeal Joint of the Fingers. Orthop., 4:175, 1981.
- ³⁹ Urbaniak, J.R.: Prosthetic Arthroplasty of the Hand. Clin. Orthop., 104:9, 1974.
- ⁴⁰ Vahvanen, V., and Viljakka: Silicone Rubber Implant Arthroplasty of the Metacarpophalangeal Joint in Rheumatoid Arthritis: A Follow-up Study of 32 Patients. J. Hand Surg., 11A:333, 1986.
- ⁴¹ Vainio, K.: Surgery of Rheumatoid Arthritis. Surg. Ann., 6:309, 1974.
- ⁴² Weightman, D.M.; Evans, D.M.; and Light, D.: The Laboratory Development of A New Metacarpophalangeal Prosthesis. Hand, 15:57, 1983.
- ⁴³ Zachariae, L.: Experience of Flatt Finger Joint Prostheses. Acta Orthop. Scand., 38:329, 1967.